

Development of High Efficiency, Radiation Tolerant, Thin Silicon
Solar Cell

JPL Contract 954600

First Quarterly Report

prepared by

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"This work was performed for the Jet Propulsion Laboratory,
California Institute of Technology, sponsored by the National
Aeronautics and Space Administration under Contract NAS7-100."

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(NASA-CR-149646) DEVELOPMENT OF HIGH
EFFICIENCY, RADIATION TOLERANT, THIN SILICON
SOLAR CELL Quarterly Report (Spectrolab,
Inc.) 13 p

N77-75717

Unclas

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ABSTRACT

Experimental studies examined techniques for silicon thinning which would reduce or eliminate edge tapering, the main cause of breakage in thin cell processing. A sodium hydroxide etch solution was developed which produced an essentially zero taper for 2 x 2 cm silicon blanks in a reproducible manner. Silicon etch rates for resistivities between 1 and 200 ohm-cm were determined as a function of etchant concentration and temperature.

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1.0 Summary

As-cut two ohm-cm silicon wafers were etched in sodium hydroxide (NaOH) solutions ranging from fifteen to sixty percent concentration by weight at a fixed temperature of 100°C. A peak in silicon removal rate of 10 $\mu\text{m}/\text{min}$ was obtained for thirty percent NaOH. In another test wafers were etched in various fixed concentrations of NaOH while the temperature was varied. These results indicated that relatively tight control of this variable was necessary in order to achieve reproducibility. Studies of very low concentrations (two percent) of NaOH revealed that the desired uniform tetrahedral structure occurred only at concentrations below five percent. Silicon blanks ranging from 1 to 200 ohm-cm were etched in thirty percent NaOH at 100°C and there was only minimal variation in etch rate over the silicon resistivity range used.

A process for achieving textured surfaces was then derived from this information. It consists of an initial etch in thirty percent NaOH to remove cutting damage, followed by an etch of two percent NaOH in isopropyl alcohol to produce the desired surface pattern.

2.0 Introduction

The purpose of this program is to develop the necessary technology to produce very thin (0.1mm maximum), high output ($17.5 \text{ mW}/\text{cm}^2$), silicon solar cells which will display improved radiation performance compared to present state-of-the-art devices. The major emphasis shall be in the areas of back surface field and selective etch technology. Higher resistivity ($>50 \text{ ohm-cm}$) silicon than is normally used for space flight cells will be investigated as a method for achieving the radiation objectives which are targeted as $15.5 \text{ mW}/\text{cm}^2$ after 3×10^{14} equivalent 1 MeV electrons/ cm^2 and $14.0 \text{ mW}/\text{cm}^2$ after 1×10^{15} electrons/ cm^2 .

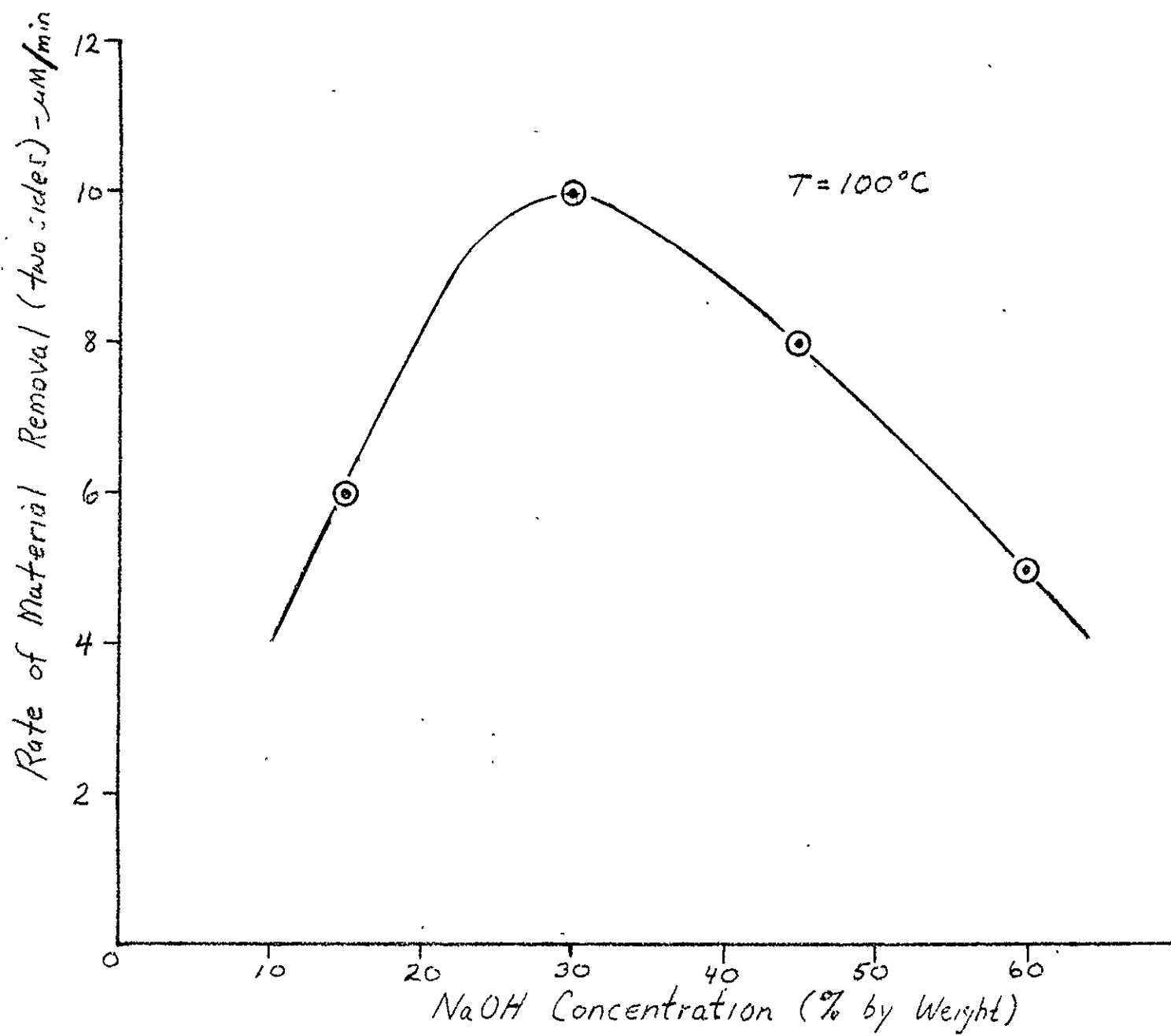
3.0 Technical Discussion

3.1 Bulk Silicon Etching

The initial objective of this program was to develop selective etching techniques for the accurate removal of silicon over the resistivity range of 1 to ~ 100 ohm-cm. Efforts concentrated on hydroxide solutions since previous work has shown them to provide a uniform thickness across the wafer, a very desirable quality for thin cell fabrication. The earlier work had shown the etch characteristics to be a function of hydroxide concentration and temperature. Hence initial experiments were performed with as-cut 2 ohm-cm material, examining etched surface structure and etch rates (thickness and outside dimension) for various sodium hydroxide concentrations at a fixed temperature. Results are plotted in Figure 1 where the rate of material removal (etch rate) is shown for both surfaces; i.e., as an overall dimensional change. This is different than similar types of studies which usually examine the etch rate on a single surface and would yield values one half of these. The thickness and outside dimensional etch rates were observed to be equal so that Figure 1 applies to either.

A rather definite peak in etch rate occurs in the vicinity of 30% concentration, with a 50 percent change in concentration providing approximately 20 percent reduction in the etch rate. Although not shown here, microscope examination of the resulting surfaces (with approximately 150μ of silicon removed) did reveal a physical difference. Typically the hydroxide etched surface, because it attacks different crystal plane surfaces at different rates (i.e., etches anisotropically) will leave a non-planar semipolished surface. These anisotropic etch rates are in turn a function of solution concentration so that the resulting structure can be varied. At the peak etch rate the surface appears to be covered by large ($\sim$ mm in extent) irregular "pillows." As the solution concentration is increased or decreased from 30 percent the "pillow" size decreases so that at very low ($\sim 2\%$) and very large ($\sim 60\%$) concentrations, very small structures are formed ($< 20\mu$ in extent). At high concentrations the resulting structures are typically rectangular, whereas at low concentrations they are tetrahedral.

Figure 1



Since a 30% concentration etches quickest, with approximately 3 minutes required for each 25 μ m removed, repeated experiments were conducted, still with 2 ohm-cm wafers, to determine the etch rate repeatability. After four additional tests, each with a fresh mixture of 30% NaOH, an average rate of 9.7 μ m/min with 0.3 μ m/min standard deviation was determined at 100°C. Considering the possible variables such as solution concentration, solution temperature, and wafer surface condition, the repeatability is quite good and along with the relatively slow etch rate (compared to the usual polishing acids) indicates good process reliability.

The impact of solution temperature was examined in a second sequence of tests, again using 2 ohm-cm material (due to availability). Concentrations of 15 and 30 percent were used, with results shown in Figure 2. The temperature dependence is quite strong with a five degree spread (around 100°C) for the 30% solution providing approximately a 20 percent rate change. In practice rudimentary methods (hot plate and thermometer) are limited to $\pm 2^\circ\text{C}$ tolerance, and a properly designed system should limit this to less than $\pm 1^\circ\text{C}$.

At this point blanks of varying resistivities were assembled in order to determine 1) etch rates as a function of resistivity, and 2) if any structural etch differences would occur. Samples selected were nominally 2, 10, 40, and 150 ohm-cm, thereby spanning the range from 1 to 200 ohm-cm. Etching was performed simultaneously in a single solution of 30% NaOH at 100°C. The total etch time was 20 minutes with the removal of approximately 200 μ m. The results shown in Figure 3 show an essentially flat distribution with a possible slight rate decrease as the resistivity decreases. Ovals are shown for the data points in order to reflect the range of material resistivities included within each group. As with the previous etch data, average etch rates for relatively long etch times are presented, so as to minimize the impact of initial wafer surface condition, such as sawn, lapped, polished, etc., which might be expected to produce some short period etch rate differences. A cursory look at different initial surface textures did

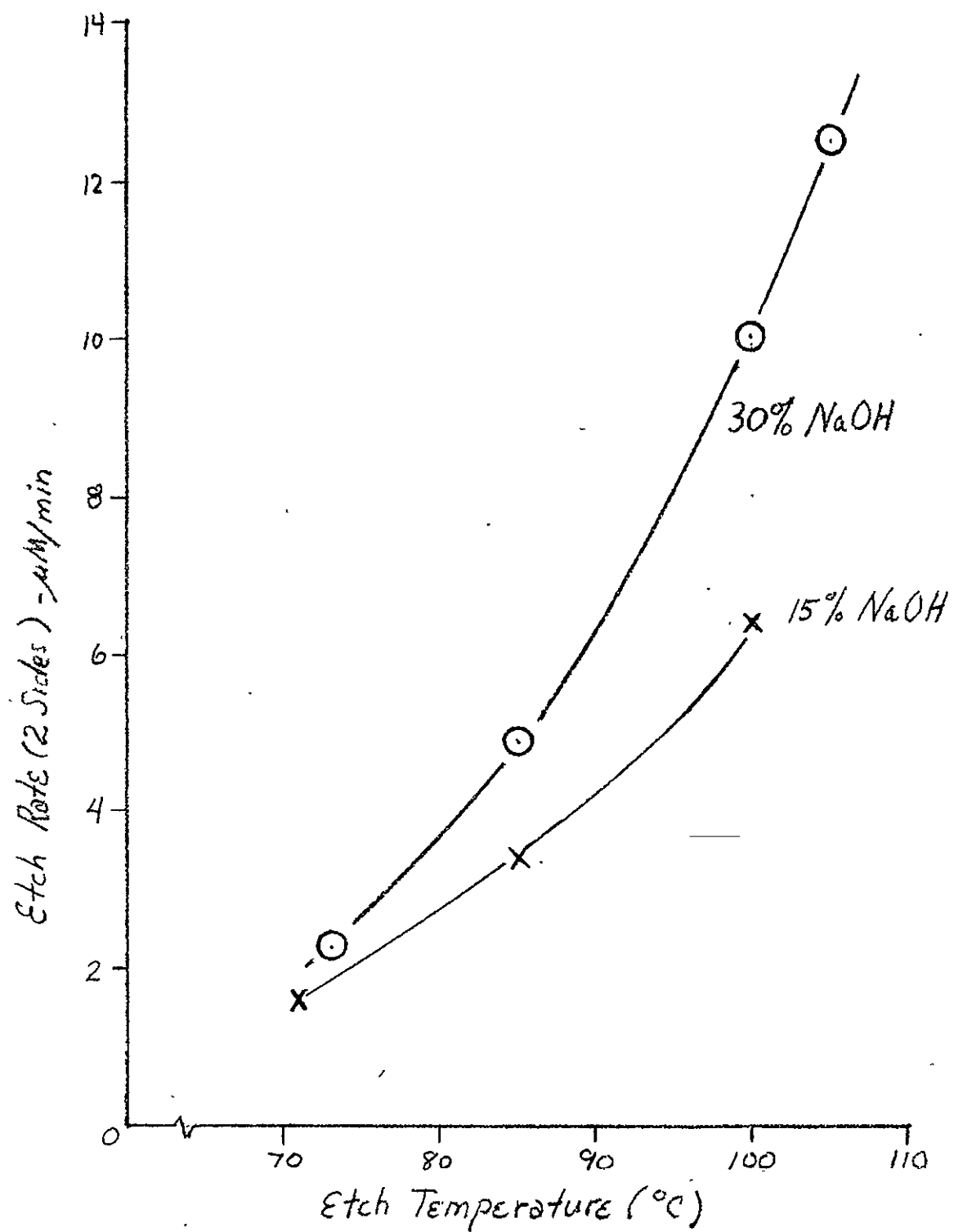
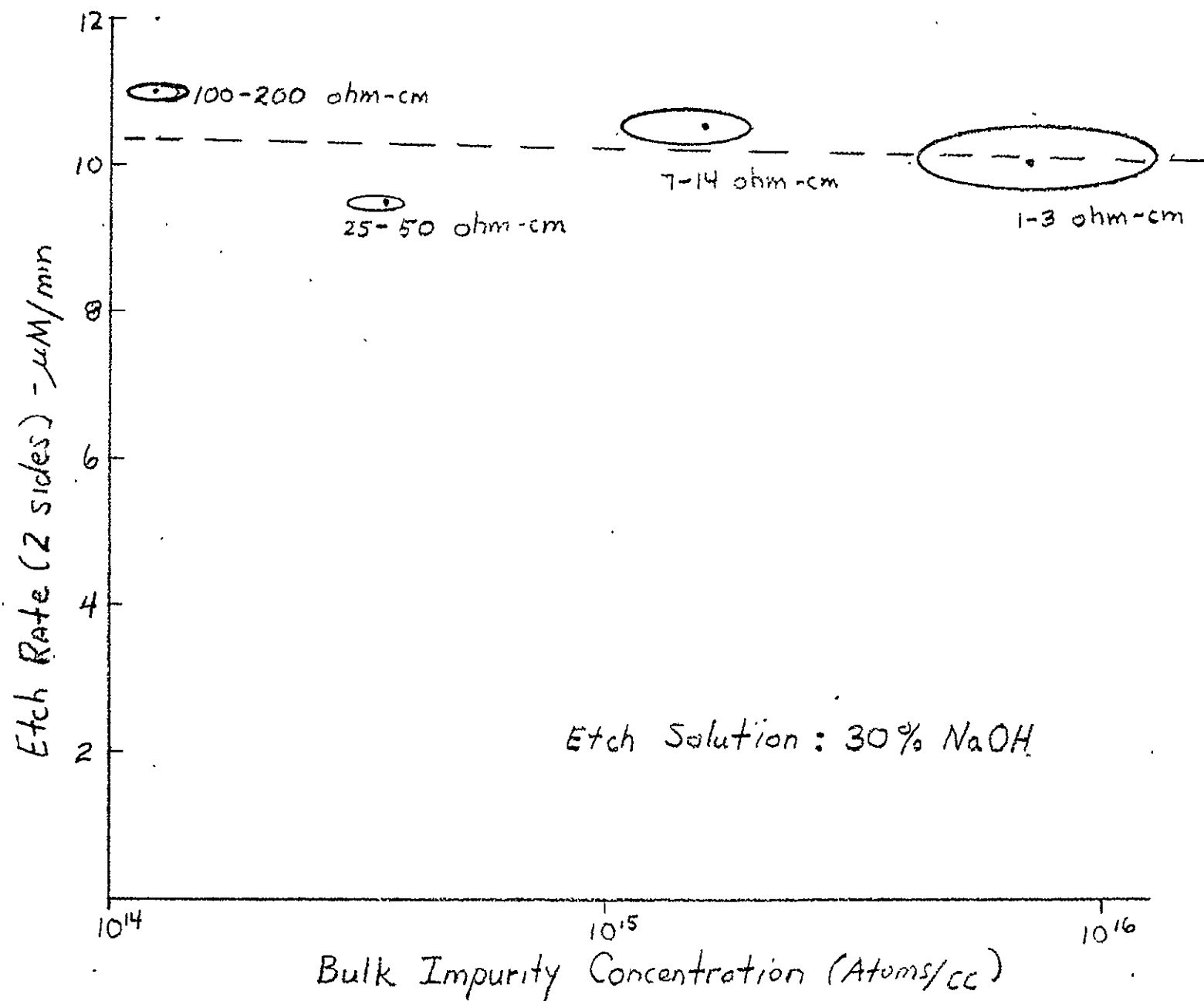


Figure 2

Figure 3



not provide any significant discrepancies for etch periods as short as 3 minutes, so that initial surface condition is not considered critical for this work.

3.2 Surface Texturing

The objective of this task was to develop a textured surface starting from a semipolished surface as previously described. The standard texturizing etch used at Spectrolab, namely a 2% NaOH solution with isopropyl alcohol, was used for the initial experiment. Semipolished 2 ohm-cm wafers were tested first, being etched in accordance with normal methods. The resulting surfaces were considered to be fully textured. This test was then repeated using samples obtained from the previous work with resistivities covering the range 1 to 200 ohm-cm.

Following the texturing etch all samples were examined visually both with the unaided eye and at 400X magnification. No visible differences were noted and all samples were properly textured. A measurement of wafer thickness indicated that the texturing etch provided an additional dimensional reduction of 0.6 $\mu\text{m}/\text{min}$.

4.0 Conclusions

Although the unavailability of key personnel caused a delay in initiating this contract, experience gained from other in-house programs allowed us to complete the bulk and surface etching phases in a cost effective manner. The technology for etching silicon wafers to thicknesses of 0.1mm without creating blank tapering has been demonstrated. It has also been shown that the sodium hydroxide etch parameters can be adjusted to achieve very thin silicon blanks with controlled outside dimensions. This has been done repeatedly for silicon samples with resistivities ranging from 1 to 200 ohm-cm.

The surface texturing process has been reduced to practice by using a low concentration sodium hydroxide etch in conjunction with isopropyl alcohol. This technique produces ordered tetrahedral patterns on the thin silicon wafers without any significant influence on outside dimensions. Silicon blanks having resistivities from 1 to 200 ohm-cm have been successfully textured, thus satisfying the surface finish goals of this program.

5.0 Recommendations

Spectrolab feels that in view of the rapid progress made in the initial stages of this program, the initial Program Plan submitted for review be approved and the cell fabrication and analysis phase of the program be accelerated. This will allow more time to be devoted to the technology for producing very thin (0.025mm) silicon blanks.

6.0 New Technology

Spectrolab has no new technology to report, since both the sodium hydroxide and sodium hydroxide-isopropyl alcohol etchants have been well documented in the literature. The application of this work to the higher resistivity range for silicon (>20 ohm-cm) has not been reported, but its technological significance is yet to be determined.

7.0 Projected Work - Next Three Months

During the next quarter we should complete Task II, Cell Design and Fabrication, which will put the program approximately two months ahead of schedule.

There will be three deliveries of cells made, including the first milestone delivery originally planned for the end of the first quarter. Pilot line fabrication will be starting at approximately the end of the second quarter. A recent development in back surface field technology made on a NASA Lewis Research Center contract (NAS3-20029) will allow us to accelerate the contract by the two months originally projected for this subtask.

8.0 Projected Work-Next Six Months

Pilot production, Task III, should be concluded including the fourth milestone delivery. Work on Task IV, preparation of 0.025mm silicon blanks should be started at the beginning of month eight, an acceleration in the original schedule by one month. Task V, assessment of large scale production will begin during month seven, two months ahead of the original projection made in our Initial Program Plan.